SUMMARY OF THE INVENTION

The present invention is directed to an in-vacuum exposure shutter that is capable of shuttering a large footprint light beam in a short time in a vacuum environment. The in-vacuum exposure shutter can be employed in any process or product that requires precise temporal control over a large footprint light beam.

In one aspect, the invention is directed to an exposure device that includes:

a source of radiation that generates an energy beam;

a shutter that includes (i) a frame defining an aperture toward which the energy beam is directed and (ii) a plurality of blades that are **fixedly** secured to the frame; and

means for rotating the **[shutter]** **frame** to cause the plurality of blades to intercept or allow the energy beam to travel through the aperture.

In one embodiment, each blade has a substantially planar surface and the plurality of blades are **fixedly** secured to the frame such that the planar surfaces of the plurality of blades are substantially parallel to each other. The exposure device is particularly suited for operation in a vacuum environment and can achieve shuttering time from about 0.1 second to 0.001 second or shorter.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates an embodiment of the exposure shutter of the present invention;
Figure 2 illustrates the shutter frame;
Figures 3A and 3B illustrate operation of the shutter**[blades]**; and
Figure 4 illustrates a photolithography system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 illustrates an embodiment of the exposure shutter which includes a support stand 7 onto which is secured solenoid 2 by solenoid cover 3 and solenoid bracket 6. The output shaft 2A of solenoid 2 is connected to shutter frame 8 by a solenoid mount 5, rotary feedthrough 4, and shaft coupling 9. For non-vacuumoperations, any suitable rotating device can be employed, for vacuum operations an electrically driven motor or solenoid is preferred. The rotary feedthrough is also preferably employed for vacuum operations. A preferred rotary feedthrough is a ferrofluidic feedthrough which comprises a ferrofluidic seal which pr vides a hermeti seal against gas and other contaminants in vacuum conditi ns

where a rotary shaft has to be sealed. Ferrofluidic feedthroughs are commercially available from Ferrofluidics Co. Nashua, N.H. For vacuum operations, the solenoid is preferably encased in housing 1 that is essentially impermeable to gas. The housing entraps contaminants that may be discharged from the solenoid.

The shutter frame 8 supports a plurality of shutter blades (not shown) which can intercept radiation (e.g., energy beam) as the frame rotates about center axis x where the frame is attached to the shaft coupling 9 which functions as a pivot. By "energy beam" is meant any flux of electromagnetic radiation (coherent or incoherent) of any frequency including visible light. The shutter frame or wheel includes two circular ring-like members 10,11 that are rigidly held together by a plurality of posts 12 onto which shutter blades are attached. The shutter frame is preferably made of any lightweight metal such as aluminum.

Figure 2 illustrates a partial cross-sectional view of the shutter frame 8 showing the plurality of posts 12 supporting shutter blades 26. The shutter frame should be sufficiently stiff to ensure that there would be little deformation due to the force of the tension created by the shutter blades. One method of attaching a shutter blade is to pass aluminum strips through the rectangular slots 24 in the side between the posts 12 and then winding the strips tightly around the posts. Epoxy is then applied to the flats created by the slots. Thereafter, the strip is held with the weight of the frame providing the force that maintains the strip substantially planar as the epoxy cures. Once the epoxy has cured, excess strip is trimmed off and the process is repeated until all the shutter blades are fabricated. The shutter blades should be parallel to each other so that there is minimum attenuation of the radiation when the shutter device is in the open position.

The shutter blades are made of thin strips of any suitable material that is non-transparent to the radiation of interest. For example, the blades can be made of metal such as aluminum, steel, nickel, or titanium or plastic such as vinyl, polytetrafluoroethylene (e.g., TEFLON), polyimide (e.g., KAPTON), polyester, polyamide (e.g, NYLON), or polypropylene.

The thickness of the shutter blades will depend on, among other things, the wavelength of the radiation and its intensity. Preferably, the shutter blades will be as thin as practical in order to minimize attenuation. Where the radiation is extreme ultraviolet EUV radiation having a wavelength of about 10 nm to 20 nm (EUV) the thickness of a metal shutter **blade** will typically range from 0.002 mm to 0.2 mm. The width of each shutter blade will typically range from 0.5 cm to 10 cm.

period of time ranging fr m 0.001 second t 0.1 second, or shorter. For EUV photolithography applications, this time period preferably ranges from 0.010 second to 0.001 second or shorter. Aside from the fully "open" and "closed" positions, it is understood that the solenoid can also be designed to move the shutter frame in and out of "intermediate" positions where the radiation is only partially intercepted. Another technique of increasing the speed of the shutter frame is to decrease the rotational moment of inertia about the solenoid shaft axis by minimizing the frame weight, with the proviso that it is also necessary to provide the frame with sufficient integrity and strength to withstand the force of the shutter blades that are stretched tightly between the sides of the shutter frame.

An exposure shutter similar to that shown in Figure 1 was fabricated and tested to shutter a visible light beam that had a diameter of approximately 4 inches (10.2 cm). The solenoid used was model Ultimag 5EM from Lucas Control Systems Products, Vandalia, OH. The rotary feedthrough was model SS-188SLAA from Ferrofluidic Co. The visible light beam was generated by a helium/neon laser. The aluminum shutter frame had a 4 inch (10.2 cm) diameter and supported 22 aluminum shutter blades that were each 0.001 in. thick (0.0254 mm) and 1 in. (2.54 cm) wide. The shutter blades were spaced 0.15 in. (0.38 cm) apart. For this configuration, there was less than 1 %. transmittance loss (i.e., attenuation) when the shutter blades were in the open position. The activated solenoid rotated the shutter frame 10 degrees in about msec to completely shutter the light beam. A feature of the exposure device employing the shutter blades is that the shutter blocked light nearly simultaneously as the shutters closed. This is in contrast to iris type shutters that block the light from the outside in and to the slide type of shutters that block the light from one side to another. Another feature of the shutter is that in the closed position it requires no power to be applied which limits heat generation, wear of the solenoid, and contamination.

Although only preferred embodiments of the invention are specifically disclosed and described above, it will be appreciated that many modifications and variations of the present invention are possible in light of the above teachings and within the purview of the appended claims without departing from the spirit and intended scope of the invention.

ABSTRACT

An in-vacuum radiation exposure shutter device can be employed to regulate a large footprint light beam. The shutter device includes (a) a source of radiation that generates an